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## Intracluster Planetary Nebulae in the Virgo cluster

K.C. Freeman<sup>1</sup>

M. Arnaboldi<sup>2</sup>, M. Capaccioli<sup>2</sup>, R. Ciardullo<sup>3</sup>, J. Feldmeier<sup>3</sup>, H. Ford<sup>4</sup>,  
 O. Gerhard<sup>5</sup>, R. Kudritzki<sup>6</sup>, G. Jacoby<sup>7</sup>, R.H. Méndez<sup>6</sup>, R. Sharples<sup>8</sup>

<sup>1</sup>*Research School of Astronomy & Astrophysics, Mt. Stromlo  
 Observatory, Canberra, Australia*

<sup>2</sup>*Osservatorio Astronomico di Capodimonte, Naples, Italy*

<sup>3</sup>*Penn State University, University Park, U.S.A.*

<sup>4</sup>*John Hopkins University, Baltimore, U.S.A.*

<sup>5</sup>*Institute for Astronomy, University of Basel, Binningen, Switzerland*

<sup>6</sup>*Munich University Observatory, Munich, Germany*

<sup>7</sup>*Kitt Peak National Observatory, Tucson, U.S.A.*

<sup>8</sup>*University of Durham, Durham, U.K.*

**Abstract.** We briefly describe the properties of the confirmed spectroscopic sample of the intracluster planetary nebulae recently discovered in the Virgo cluster. We find 23 “*bonafide*” intracluster planetary nebulae, and 8 high redshift ( $z \sim 3.1$ ) Ly $\alpha$  emitters identified by their broad asymmetric emission line.

### 1. Introduction

Planetary nebulae (PNe) are excellent tracers of very diffuse stellar populations: e.g. outer region of early type galaxies (Ciardullo et al. 1993, Hui et al. 1995, Arnaboldi et al. 1998), and of the intracluster stellar medium in cluster of galaxies. With 4 meter telescope one can detect individual PN and measure their velocities out to 20 Mpc.

How are extragalactic PNe identified? Images of a cluster field or in the outer region of galaxies are acquired with a narrow filter whose central wavelengths coincide with the redshifted 5007 Å [OIII] emission line of a PN belonging to the system. The bandwidth  $\Delta\lambda$  is taken to be  $6\times$  the velocity dispersion of the system under study; this width corresponds to  $\Delta\lambda = 40$  Å for large ellipticals and to  $\Delta\lambda = 65$  Å for the Virgo cluster field. Then an off-band image is taken in the adjacent continuum of the [OIII] 5007 Å line with a bandwidth of 200 – 1000 Å. With 4 meter telescopes on observing sites with  $\sim 1''$  seeing, a 5 hrs on-band image gives detections complete to  $F_{5007} = 5 \times 10^{-17}$  ergs cm<sup>-2</sup> s<sup>-1</sup> or  $m_{5007} = 27.0$ . This covers the first magnitude range of the PNLf at the Virgo cluster distance.

Most work on intracluster PNe (IPNe) has been done on the Virgo cluster (distance  $\simeq 15$  Mpc). The first spectroscopic confirmation was from Arnaboldi et al. (1996) who detected 3 PNe with radial velocities  $\geq 1300$  kms<sup>-1</sup> in the

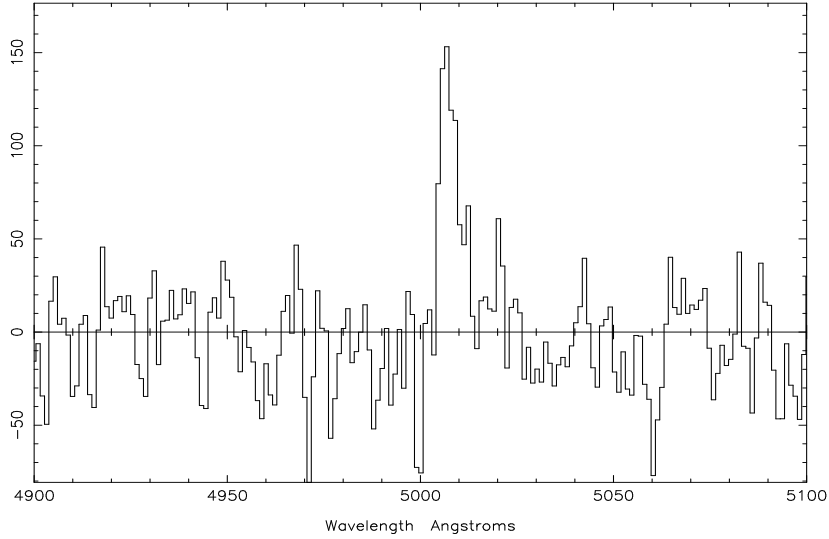


Figure 1. 2dF spectrum of a probable starburst galaxy at  $z=3.14$ .

M86 field: since M86 has a peculiar negative redshift at  $v_{sys} = -227 \text{ km s}^{-1}$ , these PNe must belong to the Virgo cluster. Méndez et al. (1997) surveyed a blank field in the Virgo cluster core with the 4 meter WHT and found 11 [OIII] emission line candidates in a  $50 \text{ arcmin}^2$  field. Feldmeier et al. (1998) surveyed several fields in the Virgo cluster and discovered 150 [OIII] emission line candidates in the  $750 \text{ arcmin}^2$  total surveyed area.

If these [OIII] emission line candidates are all associated to the 5007 [OIII] emission from PNe, one can estimate the light associated with the stellar parent population of the intracluster PNe. From the above surveys, the parent population contributes about 50% of the smoothed-out surface brightness in the cluster core. Evidence for an evolved stellar population in the Virgo cluster was also found by direct imaging of red giant stars with the HST. Ferguson et al. (1998) found 600 probable red giants in a deep WFPC2 I-band image in Virgo cluster core.

## 2. Observations

The [OIII] emission line candidates from the narrow band imaging surveys of Méndez et al. (1997) and Feldmeier et al. (1998) were observed with the 2 degree field fiber spectrograph (2dF) at the Anglo Australian 4 meter telescope. The spectra for the [OIII] emission line candidates were obtained with a spectral resolution  $R=2000$  and a total integration time of 5 hours on the 15th of March 1999. Given a target sample, the 2dF software chooses randomly out of the sample the maximum number of candidate positions to which the fibers are allocated. Some fibers were also placed on PNe candidates in the outer regions of M87, from Ciardullo et al. (1998). We got 47 detections out the 110 fibers allocated. All detections are for [OIII] emission line candidates whose  $m_{5007} < 27.0$ .

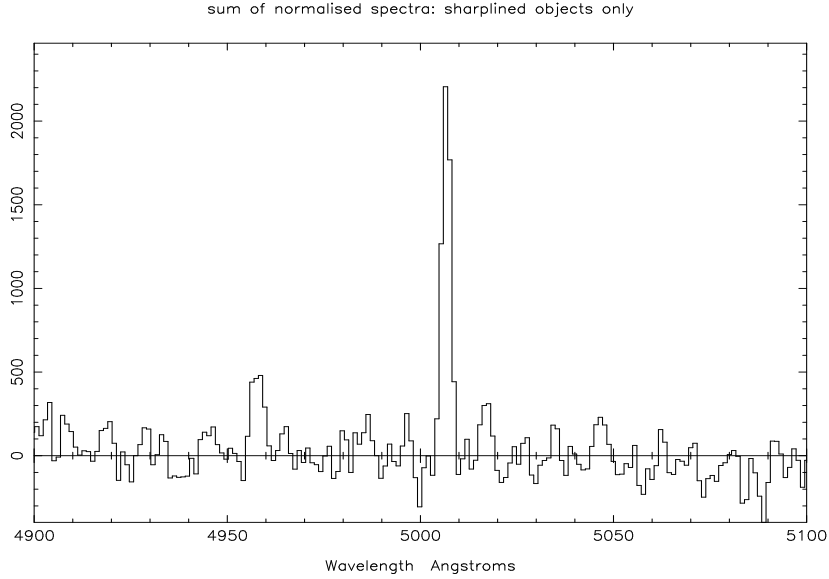


Figure 2. Sum of 23 IPN spectra in Virgo. The real fraction of IPNe is  $0.94 \pm 0.03$ .

- 23 turn out to be real intracluster PNe of the Virgo cluster. The [OIII] 4959 Å line was detected together with the 5007 Å line.
- 16 PNe were detected in the outer regions of M87 ( $\bar{R} = 24$  kpc).
- 8 spectra showed a broad asymmetric single line: probably Ly $\alpha$  from starburst at  $z \simeq 3.1$ , with an equivalent width  $W_\lambda(\text{Ly}\alpha) > 150$  Å. One of these spectra is shown in figure 1.

### 2.1. Check on reality of IPN detections

Because of the limited S/N ratio, we did not see both of the [OIII] lines in all of the 23 likely IPN detections. The PN [OIII] 4959/5007 Å emission lines have a fixed flux ratio:  $I_{5007} = 3 \times I_{4959}$ . We can use this as a way of checking on the reality of the 23 IPN spectra. For each of the 23 spectra 1) we normalise the peak 5007Å intensity to 100, 2) shift spectrum to zero velocity, 3) then add them. If all are real IPNe, i.e. not noise or redshifted galaxies with high  $W_\lambda$ , then one should expect  $\frac{I_{5007}}{I_{4959}} \sim 3.0$  in summed spectra. The observed ratio for the 23 summed spectra is  $3.2 \pm 0.1$ , so real fraction is  $0.94 \pm 0.03$ . The summed spectrum is shown in figure 2.

The spectroscopic survey of [OIII] emission line candidates in the Virgo cluster has a success rate of  $55\% \pm 17$  for candidates in the M87 field, and  $38\% \pm 8$  for the intracluster [OIII] emission line candidates with  $m_{5007} < 27.0$ . The failure to detect spectra of our candidates can be due to either to 1) candidates being not emission line objects, or 2) technical problems, e.g. differential refraction over long exposures or astrometry.

### 3. Discussion

*Velocity distribution of IPNe, M87 PNe and Ly $\alpha$  objects* – We studied the properties of the radial velocity distribution for the spectroscopically confirmed objects. For the confirmed 23 IPNe, the average velocity is  $\bar{v} = 1193 \pm 156 \text{ km s}^{-1}$  and the velocity dispersion of the sample is  $\sigma = 752 \pm 110 \text{ km s}^{-1}$ . These values are in complete agreement with those determined from the galaxy radial velocities in the Virgo cluster, i.e.  $\bar{v}_{cluster} = 1100 \text{ km s}^{-1}$  and  $\sigma_{cluster} = 800 \text{ km s}^{-1}$ . The 16 M87 PNe in our spectroscopic sample have an average  $\bar{v} = 1413 \pm 74 \text{ km s}^{-1}$  and  $\sigma = 287 \pm 51 \text{ km s}^{-1}$ . These values agree with those determined for the globular cluster system in M87, whose average velocity and sigma are  $\bar{v} = 1280 \text{ km s}^{-1}$  and  $\sigma = 340 \pm 30 \text{ km s}^{-1}$ . M87 globular clusters show  $\simeq 100 \text{ km s}^{-1}$  rotation: our PNe in M87 are mostly on the high velocity side of M87. On the other hand, the Ly $\alpha$  objects turn out to be uniformly distributed through out the velocity range allowed by the narrow filter bandpass used to select the [OIII] emission line candidates.

*On the contamination by high- $z$  galaxies* – From the narrow band imaging surveys of Méndez et al. (1997) and Feldmeier et al. (1998), the  $m_{5007}$  magnitudes of the spectroscopically confirmed candidates are all brighter than 27.0, which implies a total flux in the [OIII] 5007 line of  $F_{5007} > 5 \times 10^{-17} \text{ ergs cm}^{-2} \text{ s}^{-1}$  and  $W_\lambda \geq 150 \text{ \AA}$ , i.e. no detection in the off-band image. From narrow imaging surveys done on control fields (Arnaboldi, Feldmeier, 1999, in preparation) one would expect  $95 \pm 27$  objects per  $\text{deg}^2$  to the limiting magnitude  $m_{5007} = 27.0$ . In our sample, we expect  $14 \pm 4$  of which we would have detected  $6 \pm 2$ ; we detected 8 of such objects.

### 4. Conclusions

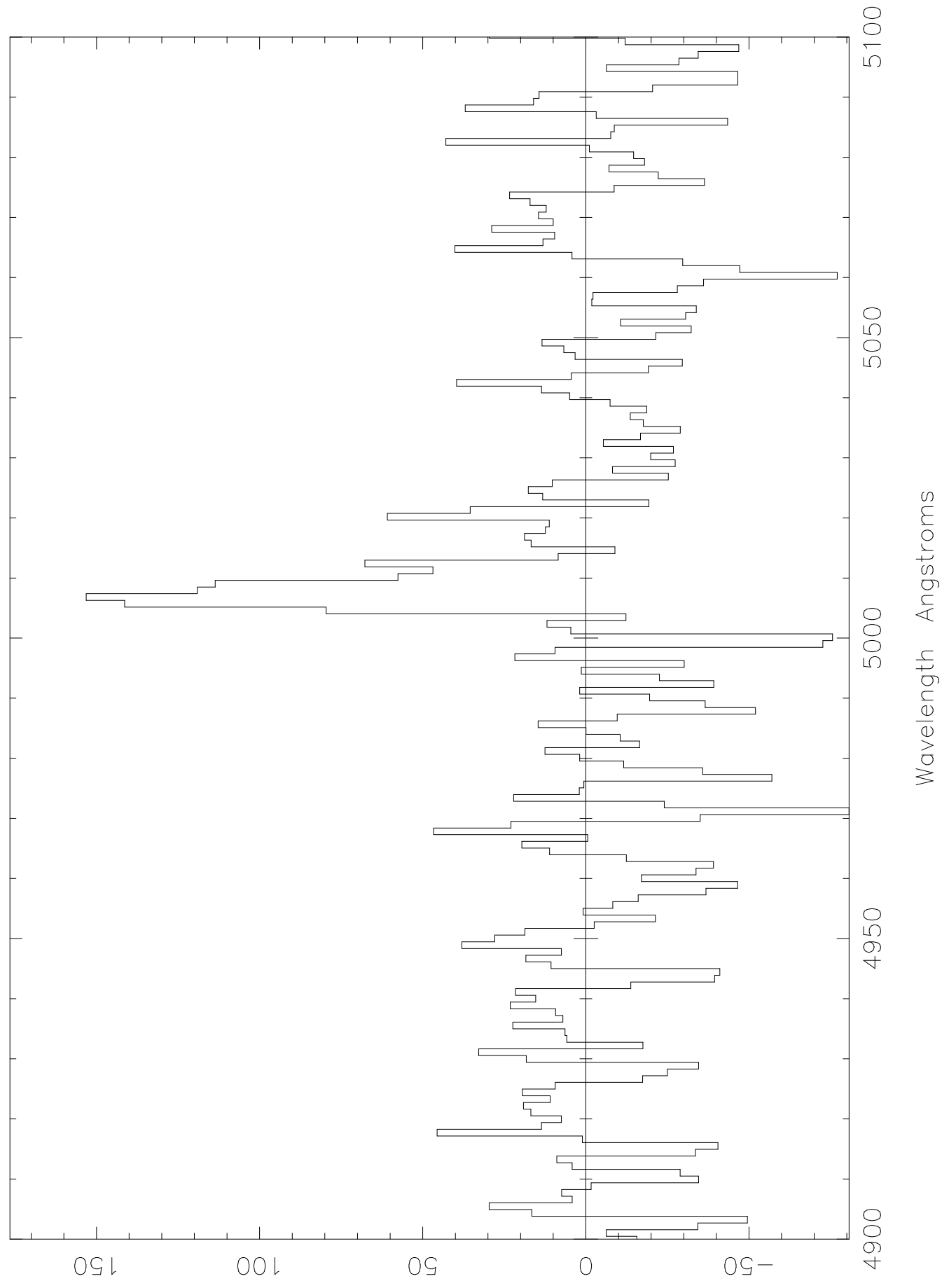
The distribution of the IPNe radial velocities in the Virgo cluster has similar  $\bar{v}$ ,  $\sigma$  to the cluster galaxies. The IPNe sample is still too small to see spatial and velocity structure - much larger survey is in progress. Of the emission-line candidates which we detected (all with  $m_{5007} < 27.0$ ), about 25% of the candidates identified in narrow band survey are high- $z$  Ly $\alpha$  emitters. The other 75% of intracluster candidates are almost all IPNe.

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sum of normalised spectra: sharplined objects only

